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## **Appendix 2**

### **Spectrum Efficient Digital Communications for 220-222 MHz Narrowband Land Mobile Channels**

as published in the Proceedings of the  
1993 IEEE Vehicular Technology Conference

Also see Section 2.1.2.2. of Appendix 1 for  
additional development and tests performed  
since the Proceedings went to press.

# Spectrum Efficient Digital Communications for 220-222 MHz Narrowband Land Mobile Channels

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**Abstract**— United Parcel Service (UPS) is continuing to expand customer services such as package tracking, on call pickup, and expedited delivery. This requires extensive communications and data processing. As part of this effort, UPS has developed 220-222 MHz land mobile radios and system technology to give its vehicle fleet high performance digital communications, with connections to the company's local area and nationwide computer networks.

In response to the FCC's initiative to promote spectrum efficiency in the 220-222 MHz band, the UPS system includes several advanced design features. These features work in close concert to allow hundreds of mobiles to operate on each individual narrowband channel.

The UPS mobile and base station radios meet the rigorous emission standards for the 220-222 MHz band, and have been granted FCC type acceptance.

Microprocessor controlled modulation enables power efficient nonlinear radios to deliver data rates of one bit per second per Hz, or higher, within a 4 kHz authorized bandwidth. Precise spectrum control allows full use of adjacent channels, with 5 kHz spacing between channel centers. Within each channel, carefully designed signaling methods allow thousands of reliable message transfers per hour.

As demonstrated in field and bench tests, the system can effectively serve both urban and rural areas, while sharing the RF band with technically and operationally diverse spectrum neighbors. Both the system design and UPS's inputs to the FCC 220-222 MHz rulemaking are based on the need for practical realization of spectrum efficient mobile radio, while providing for flexible long term application of ongoing research.

## I. SPECTRUM EFFICIENT DIGITAL COMMUNICATIONS

The FCC 220-222 MHz rules [1] provide up to six times as many voice channels per unit bandwidth as other land mobile bands. For many applications, communicating data can be conservatively estimated to yield a further improvement of at least an order of magnitude, i.e. ten times, in information capacity per unit bandwidth, compared to analog or digital voice.

UPS 220-222 MHz radios attain higher bits per second per Hz than traditional equipment. In addition, the RF modulation, detection, coding, and signaling are tailored to a narrowband, Rayleigh fading environment. For high throughput with efficient, compressed data messages, these features provide further advantages which are just as significant as RF bit rate.

As an example, UPS plans to use data transfers to provide up to the minute status on package pickup and delivery. With careful data compression, typical inbound messages will be about 0.4 seconds long. This includes data on multiple customers and parcels, with error detection and correction coding.

Fig. 1 shows timing for a typical inbound message, including control signaling, ARQ, and acknowledgments. Complete data transfer occurs within approximately 1.5 seconds elapsed time, and consumes only about 0.5 seconds on the critical path time line. Outbound message timing is similar but involves less channel control signaling. Field test results for completion times for 100 byte outbound messages appear in Fig. 2.

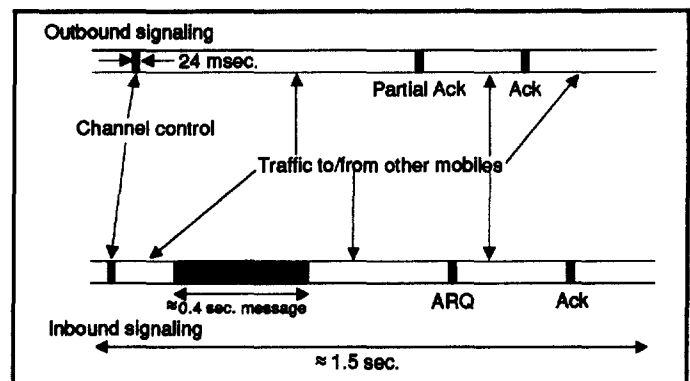


Fig. 1. Typical inbound message time line

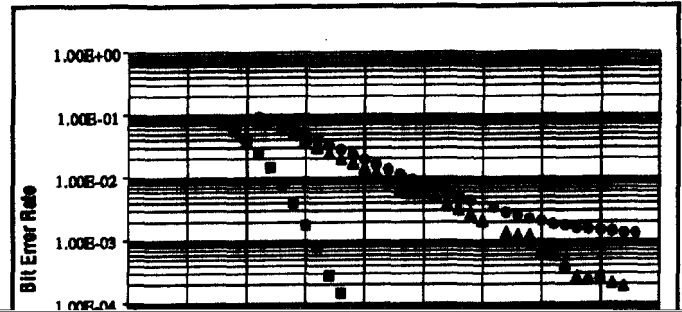
Base stations operate full duplex, and transmit continuously. Mobiles operate half duplex, sending data bursts as short as 24 milliseconds, to optimize channel efficiency. Traffic to and from multiple mobiles is interspersed for maximum throughput. The UPS system allows variable data rates, both higher and lower than the nominal 4,000 bits per second, to individually optimize each message exchange [2].

60%

base station type acceptance application, along with the FCC  
220 MHz emission mask [8, 11].

### III. LABORATORY AND FIELD PERFORMANCE RESULTS

Fig. 4 is a plot of measured bit error rate (BER) vs. input signal level for UPS radios with 4,000 bits per second multilevel FM. Fig. 5 depicts measured BER vs. cochannel interference (CCI), using 4,000 bits per second multilevel FM as both the desired and interfering signals. BER results shown here do not include error correction. Sensitivity and CCI include additive white Gaussian noise (AWGN) conditions, as well as fast Rayleigh fading with 2 Hz and 20 Hz Doppler rates. These



#### IV. CONCLUSION

In response to the FCC's initiative to foster spectrum efficiency in the 220-222 MHz band, UPS has developed narrow-band land mobile digital radio technology to provide high performance, cost effective vehicular data communications, on both a local and nationwide scale. The 220-222 MHz rulemaking, and UPS's radio and system designs, offer positive examples for ongoing evolution of standards, equipment, and systems. They also provide practical solutions for current land mobile communication requirements.

#### ACKNOWLEDGMENT

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